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Specification

Method For Producing A Ceramic Substrate

5 The invention relates to a method for the production of a ceramic substrate comprising a stack of layers stacked on top of one another.

Each of the layers of the stack contains a non-sintered ceramic material and binder, together forming a basic body, which is debinded and sintered.

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A method is known in which, for example, the decarbonization of the basic body is performed in a batch furnace, which is heated over an extend period of time to a temperature suitable for decarbonization. Then the basic body, cooled to room temperature, is removed from the batch furnace and, together with other already
15 decarbonized basic bodies, placed onto a conveyer belt and fed into a sintering furnace configured for conveyor belts. The use of a continuous process is feasible here, because the sintering is not as time-consuming as the decarbonization.

A disadvantage of the known method is that it is unsuitable for the production of
20 multi-layer substrates made of various ceramic materials having different relative permittivities and generally different coefficients of thermal expansion, in which layers with feedthroughs are provided. It was discovered that during the production of such

multi-layer substrates, cracks often occur between the feedthroughs, which are normally made of a metalliferous paste, and the ceramic layer forming the surrounding environment of the feedthrough.

5 It is, therefore, the goal of the present invention to provide a method for the production of a ceramic multi-layer substrate, in which the risk of crack development is reduced. This goal is achieved by means of method according to claim 1. Advantageous further developments of the invention are found in the additional claims.

10 The invention indicates a method for the production of a ceramic substrate, in which a basic body is made available in a first step. The basic body contains a stack of layers stacked on top of one another. The stacked layers each consist of a non-sintered ceramic material, which also contains a binder. The basic body contains electrically conductive vertical ducts, each of which passes through at least one of the layers. In a
15 further step, the layers are preferably debinded in an inert atmosphere (e.g., in an atmosphere containing nitrogen), a minimum temperature being maintained during debinding. In the ensuing step, the basic body is sintered, the sintering taking place at a temperature which is greater than the minimum temperature of debinding. The minimum temperature of debinding is dependent upon the composition of the material to be
20 debinded. Throughout the entire of the two process steps mentioned last, the temperature T of the basic body is maintained at a level that does not fall below the minimum temperature T_{EI} of the debinding.

According to the invention, both debinding and sintering are performed in one and the same furnace. This prevents the ceramic basic body from cooling to room temperature. In addition, this simplifies the method, because switching furnaces is avoided.

An advantage of the method is that it is possible to avoid cooling the basic body to room temperature between debinding and sintering. This is because cooling the basic body to room temperature between debinding and sintering holds the risk that, because of the different coefficients of thermal expansion of the electrically conductive duct and the surrounding layer, cracks can occur. As a result of the method, cooling to room temperature is avoided, also making it possible to reduce the risk of crack development. The basic body is only cooled after sintering, that is, during the stage in which the ceramic materials are already sufficiently stable, thereby reducing the risk of crack development.

Debinding is defined as a process suitable for volatilizing the organic components, especially solvents and binders, from the layers.

It is possible to perform the process steps of debinding and sintering in an air atmosphere. It is also possible to perform debinding and sintering in an inert atmosphere. Another possibility is to convert the atmosphere in the furnace during debinding in order, for example, to control the rate of oxidation of the organic components. Another possible

means of controlling the rate of oxidation is a corresponding adjustment of the furnace's temperature program, in which the direction and rate of temperature change is advantageously variable. For example, the temperature can be kept constant or reduced in some time ranges, although the current temperature must always remain above the
5 minimum temperature of debinding.

According to the invention, debinding is performed within a temperature range of $T_{E1} - T_{E3}$ ($T_{E1} < T_{E3}$), wherein the temperature in one variant of the invention can be increased, essentially monotonically, from T_{E1} to T_{E3} during debinding.

10 In the preferred variant of the invention, the temperature is initially increased, preferably monotonically, from T_{E1} to T_{E2} ($T_{E1} < T_{E2} < T_{E3}$). This step is preferably performed in an inert atmosphere, wherein unwanted oxidation of the solvents and binders can be intentionally (temporarily) reduced and/or prevented.

15 Subsequently, the atmosphere in the furnace is converted to air atmosphere. If the furnace atmosphere is converted at relatively high temperatures $> T_{E2}$, there is a risk that the oxidation of the organic components will occur too quickly and that the carbon dioxide developing in the process will emerge explosively from the layers. To prevent the
20 rapid emergence of carbon dioxide from the layers, the temperature T of the basic body can be reduced, preferably concurrently with the conversion of the atmosphere or

immediately thereafter, from $T_{E1} \leq T_{E1'} < T_{E3}$. Then the temperature is preferably monotonically increased to the final temperature T_{E3} of debinding.

This is followed by a further increase in the temperature to at least the value
5 required to sinter all layers. Only after sintering is the basic body and/or the multi-layer substrate cooled to room temperature in the furnace and then removed from the furnace.

However, the cooling of the basic body to room temperature only occurs in a stage
in which the stability of the ceramic layers is already sufficient to reduce the risk of
10 development of cracks.

Between the layers, structured metallization layers are preferably provided which,
like the vertical electric ducts, can be produced using a metalliferous paste.

15 The stack of layers stacked on top of one another is preferably a stack in which each of the layers containing ceramic material contains openings, which are filled with a metalliferous paste. The advantage of this is that the electrically conductive connections between metal layers disposed on top of one another are easily established.

20 The layers containing non-sintered ceramic material, which are normally also referred to as green foils, can already be provided with openings prior to formation of the stack. This can be achieved by means of punching, for example. Following the punching,

the openings are filled with a metalliferous paste. Only then are the green foils stacked on top of one another and is the basic body produced by means of lamination.

A paste containing precious metals, such as silver and palladium, can be used
5 advantageously as a metalliferous paste.

It is also advantageous if the materials of layers stacked on top of one another in the stack are different and the stack, therefore, contains at least two different ceramic materials. It is possible, for example, to use a ceramic material for a green foil disposed in
10 the interior of the stack which has relative permittivity of approx. $\epsilon = 20$. This makes it possible to produce ceramic substrates that contain high-capacity capacitors.

Furthermore, it is advantageous to produce the lowest and the higher layer of the stack of layers stack on top of one another by means of a ceramic material with a lower relative permittivity of, for example, $\epsilon = 8$.

15 Furthermore, it is advantageous to select the materials in accordance with the following rule:

A first ceramic material contained in the basic body begins to sinter at a
20 temperature T_{S1} . A second ceramic material contained in the basic body begins to sinter at a temperature T_{S3} . Furthermore, the metalliferous paste contained in the basic body begins to sinter at a temp T_{S2} . In addition, the following applies: $T_{S1} < T_{S2} < T_{S3}$. To

obtain a densely sintered basic body, it is preferable to sinter at a temperature that exceeds the sintering temperature T_{S3} .

Advantageously, the following can apply to the relative permittivity ϵ_1 of the
5 ceramic material with the smaller relative permittivity: $7 \leq \epsilon_1 \leq 8.5$.

In addition, the following can apply to the relative permittivity ϵ_2 of the ceramic material with the larger relative permittivity: $18 \leq \epsilon_2 \leq 22$.

10 A structured metallization layer made of the structured metalliferous paste can be provided on the uppermost layer, below the lowest layers, and between two layers stacked on top of one another. The ducts constitute vertical electrical connections between the metallization layers.

15 In the following, the invention is explained in greater detail, using an exemplary embodiment and the related figures.

Figure 1 shows, as an example, the temperature progression during completion of the method according to the invention in a chart in which the temperature is plotted over
20 time.

Figure 2 shows, as an example, a substrate produced by means of the method according to the invention, in schematic cross-section.

Figure 1 shows, as an example, a temperature profile for the use of the method according to the invention to produce a ceramic substrate. One or more basic bodies are heated for a period of three hours from room temperature to a temperature T_{E1} (beginning of debinding). In the example from Figure 1, $T_{E1} = 200^{\circ}\text{C}$. This is the level below which the temperature should not fall during the debinding. The increase in the temperature to T_{E1} can occur in an air atmosphere or, alternatively, in an inert atmosphere.

Beginning at this temperature, a large fraction of the organic components begins to escape. For this reason, the temperature is preferably increased uniformly and slowly (e.g., for approx. 13 hours), in an inert atmosphere, to a value T_{E2} . During the further process, the furnace, in this variant of the invention, is converted to an air atmosphere and, in this process, the temperature is initially reduced again to a value of $T_{E1} \leq T < T_{E2}$. Without such a temperature reduction, explosion-like deflagration can occur, which can lead to damaging or destruction of the ceramic basic body.

Following the conversion of the furnace to an air atmosphere, the decarbonization process is continued. The temperature of the basic body is now increased to a temperature T_{E3} , which is preferably 450°C and is kept constant for a period of about one hour. At this point, the last organic components of the basic body also escape. Decarbonization is then

complete. The ceramic basic body is subsequently heated, in a ramp-like fashion, to the sintering temperature T_{S1} , at which the layers 2 of a first ceramic material begin to sinter.

A ceramic substrate in accordance with Figure 2 is considered for the exemplary temperature profile from Figure 1. The ceramic substrate comprises a basic body 1, which contains a stack 1a of layers 2, 3 stacked on top of one another. The layers 2, 3 stacked on top of one another contain a non-sintered ceramic material, which, in turn, contains additional organic components such as solvents and binders. In this connection, the layers 2 are preferably executed in such a way that after sintering their relative permittivity ϵ_1 is approx. 8. Another layer 3 consisting of a second ceramic material (or at least a partial layer made of the second ceramic material) is disposed between the two layers 2. The second ceramic material is a ceramic material (preferably a so-called K20 material) with a relative permittivity ϵ_2 that differs from ϵ_1 . The K20 material is a ceramic material with relative permittivity ϵ_2 of approximately 20. In addition, vertical openings are formed in the layers and are filled with a metalliferous paste, thereby forming electrically conductive ducts 4. Internal electrodes 6 are disposed in the individual plies of the layer 3 in such a way as to form a capacitor. The capacitor is connected, in electrically conductive fashion, with an electric component 5 on the upper side of the basic body 1.

The sintering temperatures of the materials in the layers 2 and 3, and/or in the electrically conductive duct 4, are selected in such a way that the following applies to the

sintering temperature T_{S1} of the ceramic material of layer 2, to the sintering temperature T_{S3} of the ceramic material of layer 3, as well as to the sintering temperature T_{S2} of the metalliferous paste: $T_{S1} < T_{S2} < T_{S3}$. According to Figure 1, the following applies to the temperatures:

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$$T_{S1} = 625^{\circ}\text{C}$$

$$T_{S3} = 700^{\circ}\text{C}$$

From the above, it follows that after ramping up the temperature over an extended
10 period of 40 hours, a temperature of 625°C is reached, which is the temperature at which the first ceramic material begins to sinter. The temperature is kept constant for about 2 hours, and is then quickly increased to the value $T_S \geq T_{S3}$, e.g., $T_S = 900^{\circ}\text{C}$. This brings the temperature to a level at which the layers 2, 3 of the ceramic basic body are densely sintered. At the same time, namely during the temperature increase from T_{S1} to T_S , the
15 layer 3 of the second ceramic material, with a sintering temperature of T_{S3} , as well as the metallic duct and the internal metal coating begin to sinter. This temperature is now held for 0.25 seconds to obtain a thickly sintered ceramic basic body.

Only after all layers and materials of the basic body are sintered is the temperature
20 gradually reduced to room temperature if applicable Figure 1.

At least one of the layers of the first ceramic material can form a stratified compound with at least one of the layers of the second ceramic material, wherein several of such stratified compounds are preferably formed and wherein each of the structured metallization layers is provided between the stratified compounds.

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The present invention is not limited to the production of substrates that contain K8 and/or K20 materials, but instead is applicable to all types of ceramic substrates that contain feedthroughs or electrically ducts.

List of reference symbols

1	Basic body
1a	Stack
2	Layer
3	Layer
4	Duct
5	Electric component
6	Internal electrode
T_{E1}	Minimum temperature of debinding
T_{E2}	Maximum temperature of debinding in an inert atmosphere
T_{E3}	Maximum temperature of debinding
T_{S1}	Beginning of sintering of the first ceramic layer
T_{S2}	Beginning of sintering of the metalliferous paste
T_{S3}	Beginning of sintering of the first ceramic layer
T_S	Sintering temperature of the basic body
T	Temperature
t	Time